ANL-7433

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CONTROL SYSTEM FOR TRACE HEATING ON EBR-II SECONDARY SODIUM PIPING

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

ANL-7433
Engineering and
Equipment (TID-4500)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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Idaho Division

March 1968

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ABSTRACT

The Control System for Trace Heating on EBR-II Secondary Sodium Piping is a static, solid state scan and control system for coordinated control of 76 inductive and resistive heater circuits used for heating the secondary sodium system when reactor heat is not available. The basic control is an "ON-OFF" control. Each heater section is monitored for temperature and is protected through a high- and low-temperature alarm system.

I. INTRODUCTION

A. General

The secondary sodium system of EBR-II is an intermediate closed loop between the primary sodium system and the main steam system, whose purpose is to transport heat from the primary system, which contains the reactor, to the steam generator for production of steam for driving a steam turbine and electric-power generator.

Trace heating is used on the piping and associated components for the following reasons:

(1) to raise the temperature of all sodium-system components and connected piping from ambient to 350°F prior to filling the secondary piping system;

(2) to maintain the temperature of the secondary sodium system at a minimum of 350°F during periods when the primary system is not in operation and sodium is in the pipes;

(3) to assist in maintaining the secondary sodium system at the elevated temperature of about 580°F during plant standby.

Two methods of trace heating are employed in the system. Induction heating (at a frequency of 60 Hz) is used on the longer-pipe runs where the inductive heating wire can be wound on the pipe and held in position with comparative ease and where a heavy concentration of heat is not required. Resistance heating is used on the storage and surge tanks, valves, pumps, etc., where shorter-pipe runs exist and heavy mechanical components require a greater watt density of heat than is practical with inductive heating.

The heating systems are supplied power through stepdown transformers connected to the 2400- and 480-V power systems. Figures 1 and 2 show these systems and their controls. Each heating circuit is controlled by a thermocouple located at a point which most nearly represents the average temperature of the component or pipe section being heated. The thermocouple locations are shown in Fig. 3.

In Appendix A are shown various pictures of the trace heating system.

B. History

The trace-heating control equipment that was initially installed consisted of a mechanical scanning system (stepping switches) with relays for programming and control. The maintenance on this system was extremely high. Most of the maintenance work resulted from failures or malfunctions of stepping switches or program relays. System control was unreliable, causing delays in heatup and system unbalance.

Cost estimates indicated that the initial cost of a new control system would be 125 percent of the initial cost of rebuilding the existing system.

II. DESIGN PHILOSOPHY

A. Design Criteria

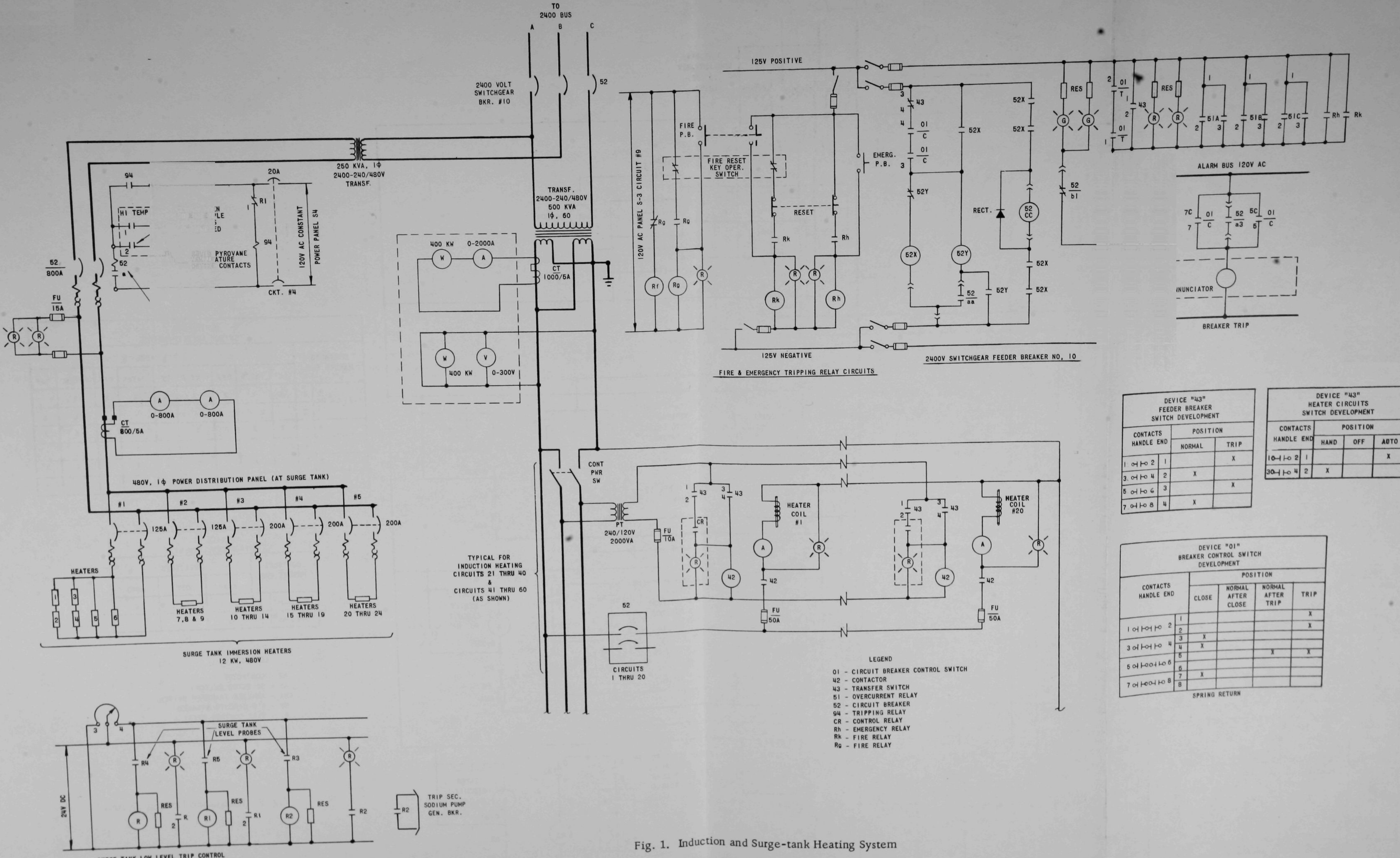
For a replacement system, the following design criteria were used:

(1) The existing panels housing the control components and input terminations had to be employed to reduce overall cost and labor requirements.

(2) The monitoring and control components had to be designed with a very high noise-rejection ratio for both static and electromagnetic noise. In addition to the inductive heating system, a large motor-generator and an AC-EM pump act as noise generators.

(3) The system had to be of modular construction for ease of maintenance and installation.

(4) Standard solid-state components had to be used to update the system for maintenance and for replacement components.



DEVICE "43" FEEDER BREAKER SWITCH DEVELOPMENT

CONTACTS HANDLE END		POSITION NORMAL	TRIP
1 ⊸⊢ 2	1		X
3 ⊸⊢ 4	2	X	
5 ⊸⊢ 6	3		X
7 ⊸⊢ 8	4	X	

DEVICE "43" HEATER CIRCUITS SWITCH DEVELOPMENT

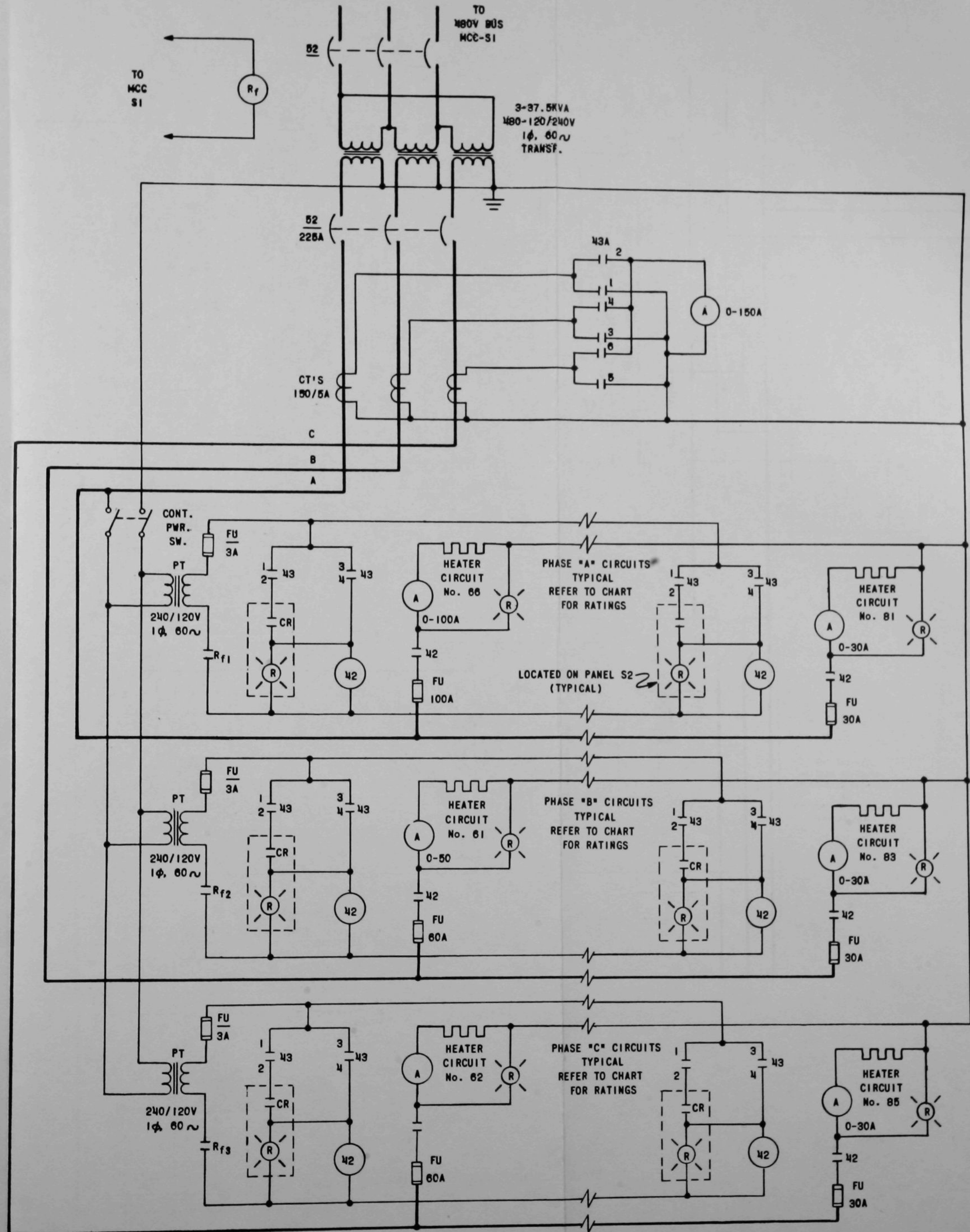
CONTACTS HANDLE END		POSITION HAND	OFF	AUTO
1 ⊸⊢ 2	1			X
3 ⊸⊢ 4	2	X		

DEVICE "01" BREAKER CONTROL SWITCH DEVELOPMENT

CONTACTS HANDLE END		POSITION CLOSE	NORMAL AFTER CLOSE	NORMAL AFTER TRIP	TRIP
1 ⊸⊢⊸⊢ 2	1				X
	2				X
3 ⊸⊢⊸⊢ 4	3	X			
	4	X		X	X
5 ⊸⊢⊸⊢ 6	5				
	6				
7 ⊸⊢⊸⊢ 8	7	X			
	8				

SPRING RETURN

Fig. 1. Induction and Surge-tank Heating System



HEATER CIRCUIT CHARTS

"A" PHASE CIRCUITS

CKT. No.	AMMETER RANGE	FUSE RATING	CONTACTOR RATING
66	0-100	100	100
69	0-10	10	30
71	0-10	6	30
75	0-10	6	30
77	0-10	6	30
80	0-30	30	30
81	0-30	30	30

"B" PHASE CIRCUITS

CKT. No.	AMMETER RANGE	FUSE RATING
61	0-50	60
63	0-50	80
64	0-10	6
65	0-10	6
67	0-10	10
70	0-10	10
74	0-10	10
79	0-50	60
82	0-30	30
83	0-30	30

"C" PHASE CIRCUITS

CKT. No.	AMMETER RANGE	FUSE RATING	[illegible]
62	0-100	60	60
68	0-30	30	30
72	0-10	6	30
73	0-30	30	30
76	0-50	60	60
78	0-10	6	30
84	0-30	30	30
85	0-30	30	30

DEVICE 43A
SWITCH DEVELOPMENT

CONTACTS HANDLE END		POSITIONS								
		"C"	INTER	OFF	INTER	"B"	INTER	OFF	INTER	"A"
1 – 2	1	X	X	X	X	X	X	X	X	
	2								X	X
3 – 4	3	X	X	X	X		X	X	X	X
	4				X	X	X			
5 – 6	5		X	X	X	X	X	X	X	X
	6	X	X							

DEVICE 43
SWITCH DEVELOPMENT

CONTACTS HANDLE E	POSITIONS	
	OFF	AUTO
1 – 2		X
3 – 4		

42
43 TCH
43A SFER SWITCH
52 BREAKER
R_f RELAY
CR r

Fig 2 Resistance Heating System

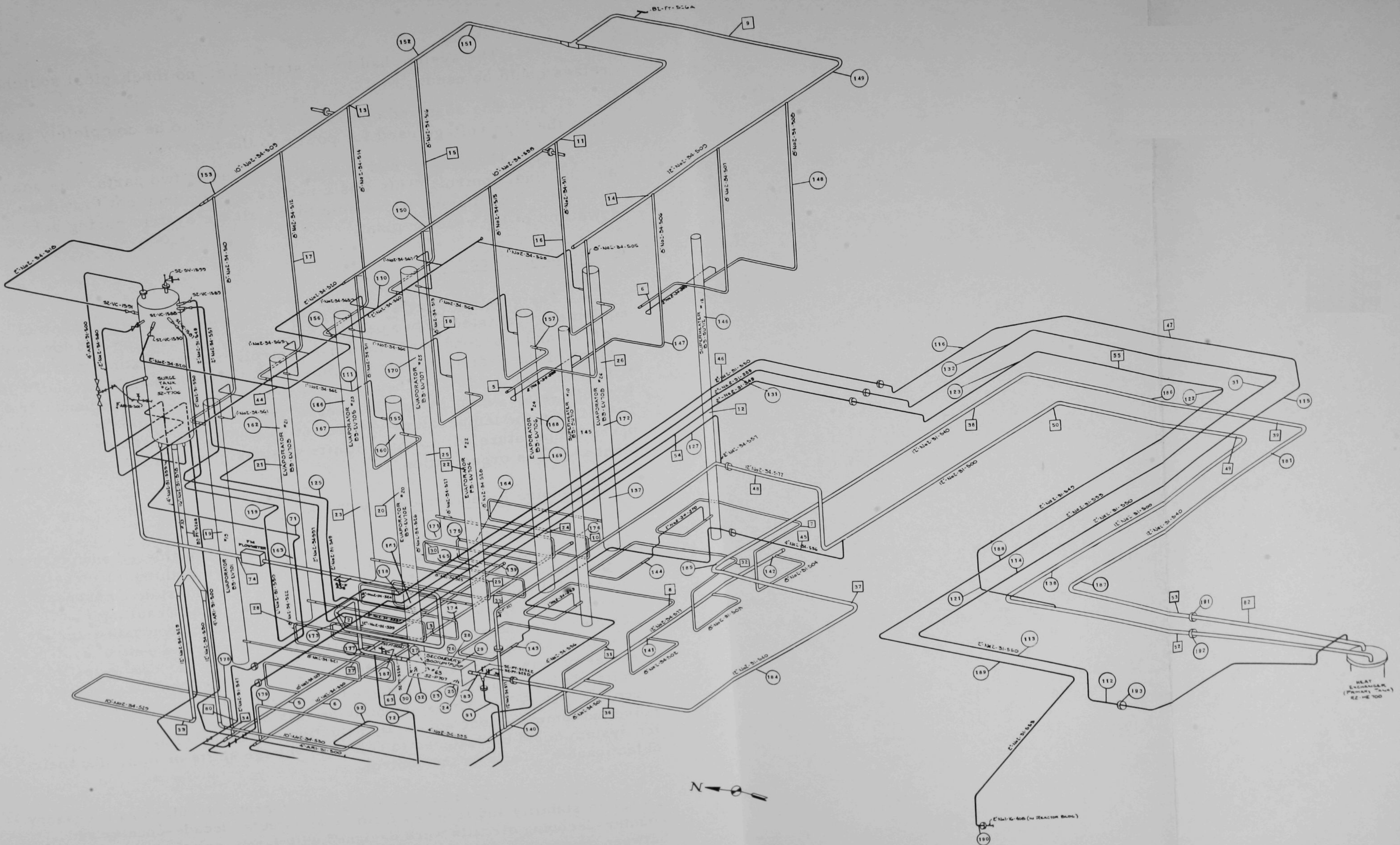


Fig. 3. Secondary-system-piping Thermocouple Locations

(5) The system had to be static, i.e., no mechanical switches or relays could be used.

(6) The scan and control functions had to be completely isolated from the high voltage used for power to the heaters.

(7) The system had to be constructed in two parts: the scanner, and the final control. This was a necessary requirement to reduce installation time, thus making it possible to install the system during scheduled downtime of the reactor plant.

B. Ambient Conditions

The existing panels for housing the scanning and final control equipment consisted of two panels: one panel for scanning and low-power control, and a second panel for final control. For approximately three months of the year the ambient temperature of these panels exceeded 100°F, with peaks up to 140°F. These temperatures were considered undesirable for solid-state components; the panels, therefore, had to be force cooled to maintain the temperature between 60 and 80°F. A system for maintaining panel temperature within these limits was designed and installed by the plant services organization.

C. High-noise Rejection and Feedback

The noise in the plant and panels was next considered and classified as (a) mechanical and (b) electrical, which included both the electrostatic and the electromagnetic noise. The selection of solid-state components eliminated the detrimental effects of mechanical noise resulting from vibration. Electrical noise was minimized through appropriate selection of components and switching method for the scanning and control systems. The choice of switching was made between pulse and dc logic gates following a series of noise tests and circuit tests in the plant. Based on the test results, dc logic gates were selected and employed in the majority of the circuits. The dc gates were found to be less susceptible to pulse (burst) noise and common mode noise. By selection of a high-voltage logic level, the system could be designed to reject dc voltage shifts or minimize their objectionable effects on the control.

The use of pulses in the timing and program circuits was necessary. To obtain stability and freedom from noise effects, decade-counter and counter-decoding circuits were designed with large isolation resistors between counters and decoders. A buffer network was used to further isolate the decade counters from the external circuits, and good grounding techniques were employed in the fabrication of component boards and assembled systems.

D. Solid-state Components

The problem of isolating a heating circuit at both input and output was considered. The control sensor for heater control is a thermocouple. For maximum accuracy and reproducibility the thermocouple could not be loaded, and because the thermocouple was grounded, both legs had to be switched. A completely solid-state switch was considered but eliminated on the basis of cost and difficulty of isolation. Relays were reviewed for the input-isolating device and a reed relay selected for the following reasons:

(1) The relay was available in multipole, satisfying the requirement for switching both legs of the thermocouple.

(2) The contact resistance was low and reasonably constant throughout the operable life of the relay. The relay would not affect system accuracy.

(3) The relay was compatible with the modular design desired.

(4) The relays could be operated from a circuit of low voltage and power.

(5) The reed relay is an encapsulated relay which eliminates the problem of maintaining contacts.

Using the reed relay for the input switch provides complete isolation of the thermocouple input circuit.

E. High-power and Control-circuit Operation

The final-control relay was next reviewed. Because most of the circuits controlled were inductive heating circuits, maintenance on relay contacts was extremely high. The 10- to 60-A contacts used were costly in both labor and material to replace. A number of relays were considered and eliminated in favor of a silicon-controlled rectifier (SCR). The SCR always switches at that point in the cycle when the current is at a minimum. The SCR is a pnpn-junction solid-state device with a very high gain. The device is readily adaptable to this application because it can be turned "ON" (made to pass a current) with a very low control current, and it automatically turns "OFF" when the anode voltage drops to zero. Because the switching, particularly "OFF" switching, occurs at the point of minimum power, the inductive kickback is controlled and the SCR does not destroy itself in arcing as does a relay.

A number of SCR's were obtained and operationally tested on an inductive circuit. It was found that a number of units were available at the desired voltage, and that by properly designing the heat sinks, SCR's would be satisfactory as the final control element. The SCR's selected were a 2N688 for heating circuits requiring 30 A or less and a 2N1916 for circuits requiring a current greater than 30 A.

F. High-voltage Isolation

High-voltage isolation between the gate controller and the SCR gate can be an equipment problem and also a personnel hazard problem. Isolation in this system was accomplished by use of a standard pulse transformer with a breakdown rating of 400 V (dc). The transformer was tested at 1000 V (dc) and found to be satisfactory. With this pulse transformer, the 240 V (ac) can be isolated from the scan and control system. In the initial testing of the SCR, the gate-circuit conductors between panels were found to measure 15 to 30 V (ac) of 60-Hz induced voltage plus low-level voltage from a frequency considerably higher. To prevent either of these induced voltages from firing the SCR, a firing frequency of 2500 Hz was used for the gate circuit. A very narrow band-pass filter was added to the final control board in order to pass only this frequency. This addition eliminated the heavy shielding requirement and made possible the scheme of pulsing the gates without synchronizing to the 60-Hz power lines.

The system design is open ended in that the number of points (inputs) scanned can be increased or decreased with the addition or removal of a few printed-circuit boards. Scanner timing is adjustable but limited to a maximum frequency of twice per second by the recovery time of the input analog amplifier.

III. SYSTEM CONSTRUCTION

To minimize plant downtime, as much of the system as possible was assembled in the shop and tested prior to installation. To accomplish this, printed-circuit-board racks were designed, fabricated, prewired, and tested, and external wiring harnesses were made up and connected at the replacement-equipment end. The design of the circuit-board racks and their panel mounting permits access to the boards from either side of the racks with the racks mounted on the panel.

Each different circuit that was designed was breadboarded and thoroughly tested before incorporation into the overall circuit. The printed-circuit boards are fiberglass sheets, 3/32 by $4\frac{1}{4}$ by $7\frac{3}{4}$ in. in size, with a copper thickness of 0.0028 in. These boards were photoetched, processed in etching solution, washed, and tinned, before mounting of components.

The assembled printed-circuit boards were rack mounted in telephone-type relay racks. Each board was numbered and arranged in the rack for a minimum length of interconnecting lead. Termination strips were mounted on each relay rack for ease of interconnecting and for trouble shooting. The racks were hinge mounted within the panel, making access possible to both the front and rear sides of the racks.

The installation was completed in two steps. Step I was the installation of the scanning and low-voltage control system. Step II was the installation of the final relay. Step I was completed and the system was in operation for approximately four months before Step II was completed.

IV. FUNCTION AND OPERATION OF SYSTEM ASSEMBLY

A. General

The control system is divided into two basic circuits: (a) the measuring circuit, and (b) the control and sequencing circuit.

The input signal to the measuring circuit is the output of a Chromel-Alumel thermocouple located on a heated length of pipe or some other component of the secondary sodium system. The input signal is conditioned and compared with a setpoint, and if it is lower or higher than the setpoint, the associated heater circuit will be turned "ON" or "OFF." The heaters will turn "ON" if the temperature drops 2.5°F lower than the setpoint or turn "OFF" if the temperature exceeds the setpoint by 2.5°F.

The system can be operated in automatic or manual control modes. The automatic mode is the normal mode for operation. In the design of the equipment, manual control was intended for use in maintenance and for resetting the operating limits.

The components available for system operation are as follows:

1. Channel Identification

Located on the front panel are two windows with lighted black numerals for identification of control-circuit channels. The numbers are read from left to right as "01" through "76." The channel identifications are used in monitoring during normal operation, in performing maintenance work on channels, and in presenting setpoints.

2. Analog Readout

The analog readout device is a voltmeter connected directly to the output of the thermocouple mV/I amplifier. The meter shows the temperature in degrees Fahrenheit of the pipe section connected to the circuit. The meter also shows the channel-setpoint temperature when the alarm or setpoint switch is depressed. The meter is used for monitoring pipe temperature during normal operation and for readout of the setpoint when adjusting the setpoint.

3. Control (Zone--Individual)

The individual heater sections can be controlled in one of two ways: (a) individual or (b) zone control. When the system is on individual control, an incoming temperature signal is compared with a voltage taken from a potentiometer assigned to that particular channel. Located under the cover of the panel are potentiometers with duo-dial operators. Located above each of the potentiometers is a light with a number. Each of these potentiometers provide the setpoint temperature for the channel indicated by the light. The light is "ON" when the heater section is energized.

When the system is on zone control, each incoming temperature signal is compared with a voltage (setpoint) assigned to a group of pipe sections. There are three such zones: Zone 1 consists of channels 1 through 20; Zone 2 consists of 21 through 40; and Zone 3 consists of 41 through 60. Channels 61 through 76 are always on individual control and are designated Zone 4.

4. Manual Scan

The automatic and manual systems share common equipment--primarily the equipment for point selection and for advancing from one point to the next. To step manually through the various channels, the auto-manual button is depressed and held depressed while the manual-scan button is depressed and released once for each channel.

5. Point Selection

Point selection is actuated by the automanual scan button in conjunction with the digital switches mounted on the front panel. Point selection is used for monitoring a specific point at the convenience of the operator, rather than the system. The advance to the point selected is at double the normal scanning rate.

6. Reset

The reset button is used to reset the scanning system to channel "00" at any time during the scanning cycle. This feature is provided mainly for convenience for the operator.

B. Measuring and Control Functions

1. Measuring Circuit and Low-level Control

The thermocouple output signal, which is proportional to the pipe temperature, is programmed for sequential inputs to the measuring circuit. Through operation of the timing and sequencing circuit, the proper relay is selected when the alarm driver closes the contacts on a particular relay. The thermocouple output signal is thereby introduced to the measuring circuit for processing (see Fig. 4).

2. mV/I Converter

The mV/I (millivolt to milliampere) converter is a standard Leeds and Northrup "M-line" mV/I converter. It is used here as a voltage amplifier for amplifying the 0- to 22.26-mV input to 0 to 10 V (dc) at the output of the converter. This output has at this point been conditioned to 10 mV/°F. The output (0 to 10 V (dc)) is fed in parallel to three comparators as follows: (a) a heater-control comparator, (b) a high-alarm comparator, and (c) a low-alarm comparator. The output is also read on the analog voltmeter for an indication of the heated-section temperature.

3. Comparator (Operational Amplifier or "OA")

The comparators are operational amplifiers which are operated as devices for comparing a conditioned parameter signal with a setpoint signal.

The comparators must keep the control and alarm circuitry aware of the differences between the parameter (input) signal and the setpoint signal. Two states are normal to a comparator. These are as follows: (a) The input signal may be of lower voltage than the setpoint signal; the comparator will then keep the operational amplifier biased "OFF" or at a zero output. (b) The input signal may be of higher voltage than the setpoint signal. In this case the operational amplifier will be biased so that the output is at a high voltage level with respect to the zero or "OFF" level.

The comparator is then used in this circuit to perform two specific functions: (a) high alarm or control, and (b) low alarm or control. In the case of the high alarm or control, if the signal equivalent to the input parameter exceeds the preset level of the setpoint, the operational amplifier is biased "ON" and the output voltage is greater than the zero voltage. In the case of the low alarm or control, if the signal equivalent to the input parameter is less than the signal for the setpoint, the operational amplifier is biased "ON" and a high output signal is presented to the balance of the control circuitry. The action here would be to energize the heater, adding heat to the system until the pipe temperature exceeded the setpoint and caused signal action that would turn off the heater.

Referring to Fig. 5, the setpoint signal is presented to the comparator at point 4. The signal equivalent to the input parameter is presented at point 6. The two signals are compared and the differences (sum) fed to Q1 through point 15. Transistors Q1 through Q6 are in effect the operational amplifiers. The output of the amplifier is at point (B) which is connected to point (2) on the insert circuit or isolation amplifier.

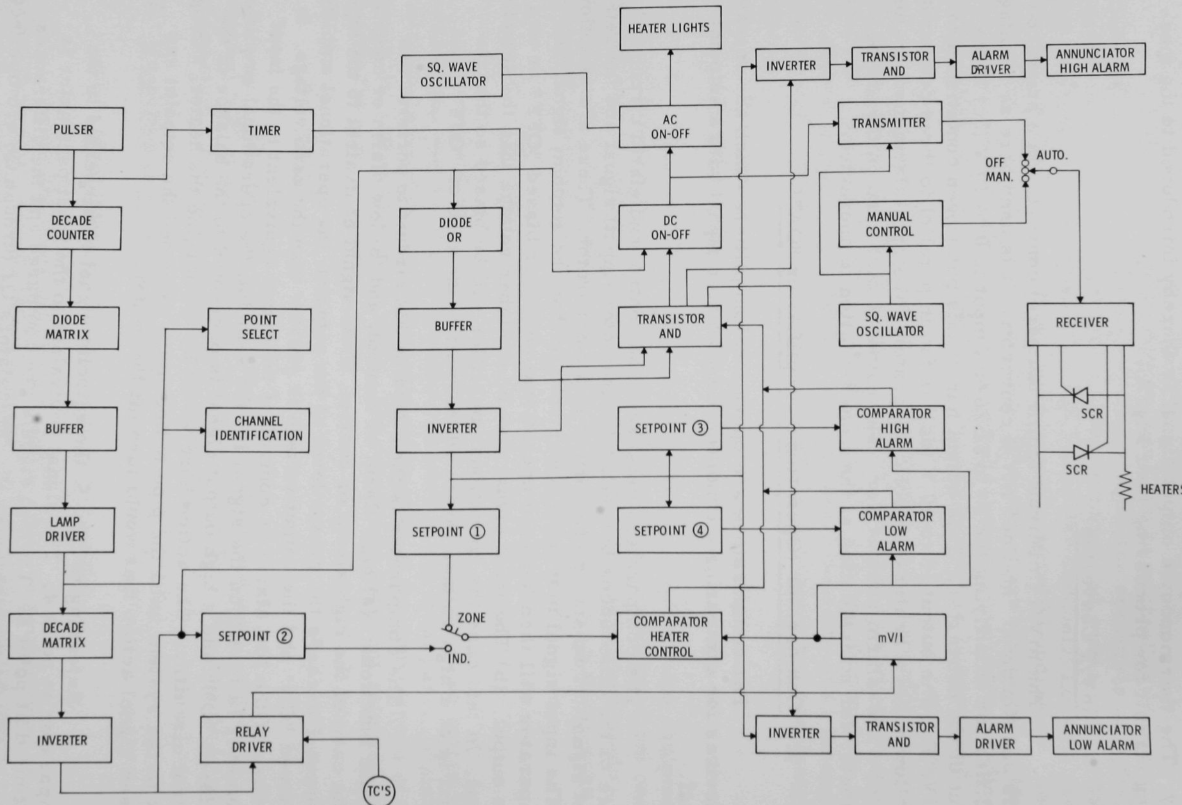


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Fig. 4. Trace Heating Control Block Diagram

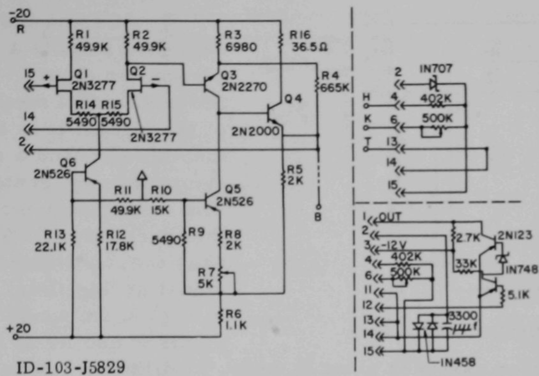

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Fig. 5. Operational Amplifier

The output from the "OA" board will be a zero or a one level of voltage, depending on the state (off or on) of the operational amplifier. This output is connected to a transistor "AND" board.

4. Transistor "AND" Board (TA)

The signals that feed into the operational amplifier are analog signals. In the operational amplifier these are converted to another domain which involves only two levels of signal, zero or one. A further transformation is then required to combine this output with time conditions.

With a scanning system, we require that the equipment maintain a time schedule. Within this schedule must occur the sequences necessary to: (a) measure the input signal level, (b) condition this signal, (c) compare it to the setpoint, and (d) align the control equipment and maintain this alignment until a new set of events can be sampled.

Because much of the equipment must be shared, a common time must be introduced into the system to maintain the identity of a specific input parameter. A memory is required also. The control equipment must remain in the position where last set or remember what the condition of the input parameter was when last contacted.

To provide this memory chain, time as well as input-parameter conditions must be introduced in the digital domain of zero and one. In the transistor "AND" board (see Fig. 6), two events must occur. One, a signal must be present at input No. 1, point P, and, two, a signal must also be present at input No. 2, point R. Point P is connected to the output of the operational amplifier, point R to the timing circuit. Both P and R must have signals before the "TA" can operate.

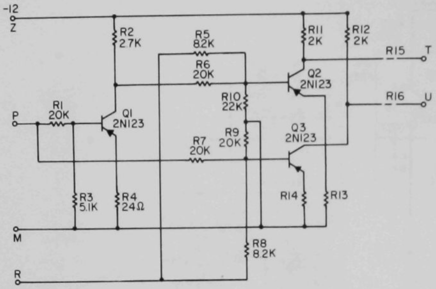

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Fig. 6. Transistor "AND" Circuit

At some instant, the timing sequence selects a specific input-parameter signal. Immediately the input mV/I measures the level of the signal, it is compared against the setpoint, and a zero or one voltage is then presented at the "TA." The timing sequence has informed this particular "TA" that it should pass the conditioned input-parameter signal at this time. Referring again to Fig. 6, we would have inputs at points P and R. If a signal for one alarmed condition exists at point P, point T will have a "one" or voltage level output. If the input signal is normal, a voltage level will exist at point U. This part of the system can only be active during the time an input exists. Once the scanner moves off this point, both outputs will return to the normal or deactivated state to be ready for the next input parameter in the sequence.

From this board, we can have one of two output signals. One signal identifies an abnormal condition, and the other a normal condition. It should be noted that all components reviewed so far are common to all of the input parameters. From this point on through the digital domain, each input-parameter signal will have assigned output components. The outputs of the transistor "AND" board are fed to inverters for the alarms and to the dc "ON-OFF" board for heater control. The "ON-OFF" board will be described next.

5. "ON-OFF" Control Board (CB)

In the preceding stages, the decision was made as to the status of the input parameter. Either the input parameter was within the setpoints (no alarm) or outside the setpoints. In the latter case, we must preserve the information as to whether the input parameter was high or low, and we must make this information available for the operating personnel and the system.

A review of Fig. 7 will show that the "ON-OFF" control board is a bistable amplifier circuit. Once energized by an "ON" signal of significant duration, the amplifier will turn "ON" and remain "ON." Simultaneously with one amplifier turning "ON" the other is turned "OFF." Note input possibilities at points C and J. Note also a center tap, marked "permit." The permit input is connected back to the timing circuit. Only when the permit circuit is completed can the state of either of the bistable amplifiers be changed.

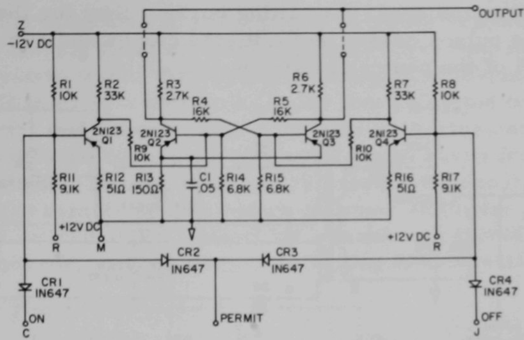

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Fig. 7. ON-OFF Control

Operation of the component is simple in that a given condition energizes one or the other of the two states. Either state remains energized until a change occurs in the form of a pulse to the "ON" or "OFF" units. Thus, if a heater is turned "ON" it will remain "ON" until the next time this particular heater circuit is scanned. If "OFF" the heater remains "OFF" at least until a scan in which the temperature measurement indicates additional heat is required.

The output of the bistable multivibrator is a low-energy signal which is not generally capable of operating a relay or lights. For this reason an amplifier is required. In this system it consists of an ac "ON-OFF" control board, or transmitter, for signal transmission to the final-control SCR's.

6. AC "ON-OFF" Control Board (ACC)

The best device which is available for control of large quantities of power is the silicon controlled rectifier (SCR). This component has inherent capabilities for switching under inductive or resistive load conditions which could not be withstood by transistors. Figure 8 is a schematic for a switching circuit used for final control of the heater "ON-OFF" indication associated with this control system. Two inputs are required for circuit operation: (a) a signal from the preceding dc "ON-OFF" controller indicating a high or low temperature, and (b) a 2500-Hz signal for gate control of the SCR's. A "one" at point B turns on Q4 and clamps Q1, blocking the 2500-Hz signal from the square-wave oscillator. No gate-control pulse is available, and the gates to the SCR's remain closed. The heater-indicating light de-energizes, implying a high temperature for the input parameter. A zero at B turns off Q4, unclamps Q1, and permits it to function as an amplifier following the 2500-Hz input signal. The 2500-Hz signal is transferred to the gate circuit through a pulse transformer with two secondary windings, one for each gate. As long as the pulses continue, the SCR gate remains open, permitting current flow for the heater "ON" light. Once the pulses cease, the SCR gate closes and current is stopped at zero or 180° of the controlled sine wave.

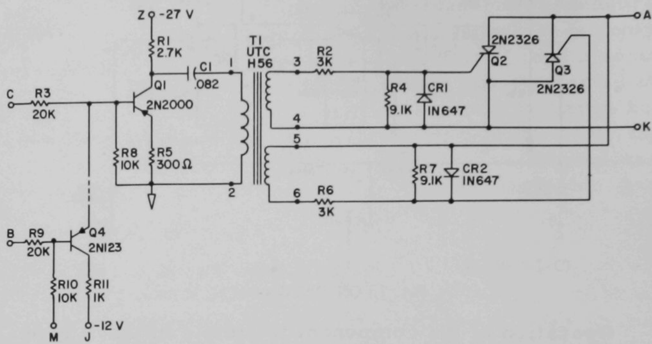

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Fig. 8. AC ON-OFF Control

The specific function performed by this board is that of providing operational information. A bank of numbered lights (1 through 76) is mounted on the front panel. As the system scans, the heater sections are checked and identified according to their state. If the heater is energized "ON," the light is lighted; if "OFF," the light is dark. The operator can determine at a glance the state of all the heaters. As stated previously, if a heater is turned "ON" it will remain "ON" until a scan in which the pipe temperature exceeds the preset temperature.

It has been mentioned that a square-wave oscillator is used for gate control of the SCR's. Before continuing with tracing the circuit, the square-wave oscillator will be discussed.

7. Square-wave Oscillator (SWO)

In Part II of this paper the problem of mechanical and electrical noise was discussed, and the 60-Hz induced voltages within and between panels were identified as an action of the 60-Hz induction heating system. Since this induced voltage would cause spurious gate operation, a filter was designed to pass a very narrow range of frequencies and essentially block all voltages of any other frequency. A filter design of 2500 Hz was selected, tested, and found to operate very satisfactorily. This frequency then had to be provided for the system. The square-wave oscillator shown in Fig. 9 was designed for the 2500-Hz signals for SCR gate operation.

Referring to Fig. 9, Q1, Q2, and their associated components form a free-running multivibrator which operates at the 2500 Hz desired. Once started, the free-running multivibrator will produce pulses at a set frequency, within reasonable limits, as long as power is available. The pulse produced has a sloping front and a trailing back edge, and, in general, lacks definition for system work. Some pulse shaping must therefore be done. A bistable multivibrator is a standard circuit ideally suited to forming clean square pulses. Q3 and Q4 comprise a bistable multivibrator to convert the free-running multivibrator pulses into pulses with sharp front rises and sharp trailing edges. These pulses are referred to as square-wave pulses. Q5 is added to the circuit as an emitter-follower amplifier for impedance matching to the ac "ON-OFF" board for a maximum transfer of power, isolation between boards, and prevention of loading of the bistable multivibrator.

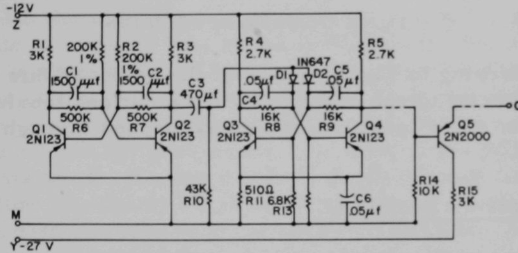

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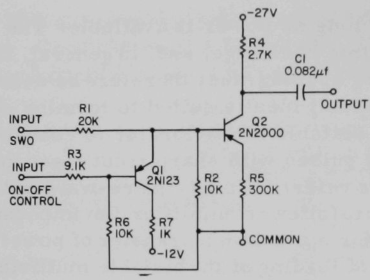
Fig. 9. Square-wave Oscillator

The circuit has been traced to this point through the operation of the lights for operator information. Referring to Fig. 4, we will return to the dc "ON-OFF" board and follow the action through to heater operation. From the dc "ON-OFF" board the signal is transferred to the transmitter.

8. Transmitter for AC "ON-OFF" (TR)

Reviewing briefly, the signal from the dc "ON-OFF" board was the signal from a bistable multivibrator and was in the form of a "zero" or "one" depending on whether the pipe temperature was higher or lower than the setpoint temperature.

Note in Fig. 4 that a square-wave oscillator signal is programmed to the transmitter board. Note also a signal from the dc "ON-OFF" board. The transmitter circuit (see Fig. 10) serves as a gate either preventing or permitting the square-wave signal to proceed through this stage to the next stage. Circuit components, R1, R2, R5, C1, and Q2 form the buffer stage for interlocking the 2500-Hz square wave. The square wave is applied to the base of Q2 through R1. If Q1 is not "ON" (conducting), then the base of Q2 follows the square-wave oscillations. If Q1 is conducting, then the square waves are locked out of the output because the gate Q2 is held on (closed) by Q1. The "ON-OFF" signal goes to Q1 through R3, and is a dc voltage of less than 0.5 V for transmitter "ON" and approximately 6 V for transmitter "OFF."



Pin Connection

A - No. 2 Output
B - No. 2 Input SWO
C - No. 2 Input ON-OFF
D - No. 1 Output
E -
F - No. 1 Input from SWO
H -
J - No. 1 Input from ON-OFF
K -
L -
M - Common
N - Common
P - -12 V
R - -27 V
S -
T - No. 3 Input from SWO
U - No. 3 input from ON-OFF
V -
W - No. 3 Output
X - No. 4 Input from ON-OFF
Y - No. 4 Input from SWO
Z - No. 4 Output

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Fig. 10. Transmitter for AC ON-OFF

Referring to Fig. 4, note that the output of this receiver board is connected directly to one of three switch positions labeled "auto." With the switch in the "auto" position, the signal passes through the switch to the receiver board.

9. Receiver Board (RE)

The receiver board is designed to accept the 2500-Hz signal from the transmitter board for SCR operations, to reject noise signals, and to provide isolation between the trigger (gate) circuit and the high-voltage SCR's serving as the final control relays.

The input signal is at points M and R in Fig. 11. The components C1, C2, L1, and L2 form a passive band-pass filter passing only 2500 ± 200 Hz. The 60-Hz induced voltages and odd harmonics of 60 Hz are rejected by the filter, leaving only the 2500 Hz necessary for gate operation. Pulse transformer "XT1" has been added to isolate the 230 V (ac) used for heater power from the low-voltage section of the circuit. SCR1 is a high-gain device added to fire the primary SCR's (SCR2 and SCR3). The gate current for control of SCR2 and SCR3 passes through SCR1, CR5, and CR6. Diodes CR2 and CR7 serve a dual purpose: (a) they block negative

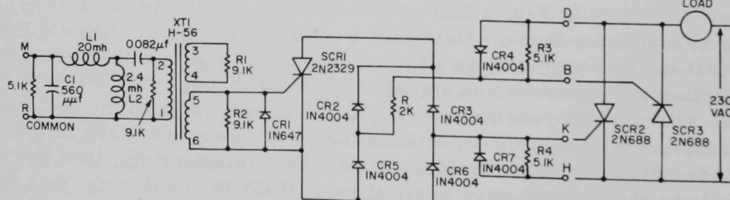

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Fig. 11. Receiver for AC ON-OFF. R is chosen to limit gate current of SCR2 and SCR3 to Ig peak; CR2-7 are chosen for ac load voltage and current; SCR1 is chosen for ac load voltage and current and o--pin connection.

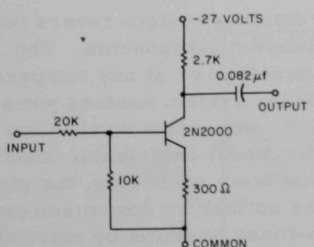
pulses from the gates of SCR2 and SCR3, and (b) they provide a low-impedance path for the positive gate currents to SCR2 and SCR3 (i.e., CR2 for SCR2, and CR7 for SCR3). Components C2 and XT1 differentiate the square wave; the gate of SCR1, therefore, sees both the positive and negative pulses. In this part of the circuit CR1 has been added to block the negative pulses. Resistor R4 has been selected to limit the gate current to less than the rated maximum gate current specified by the manufacturer for the primary SCR's.

Referring to Fig. 11, note that the primary SCR's (SCR2 and SCR3) are in parallel with each other, but reversed and in series with the heater load. With the 2500-Hz square wave applied to the gates of these SCR's, each gate is open for half of the 60-Hz power sine wave; thus, SCR2 will pass current while SCR3 is blocking, and the reverse for the other half of the sine wave. By use of this scheme, full-wave power is available for heater power. To turn off heater power, the square wave to the gate is stopped and the gate closes. As soon as the SCR sees a negative voltage at its anode, it stops conducting and through its blocking action stops current flow as effectively as open contacts of a switch. Note, though, that conduction does not stop until the anode is negative. At this time the current is at a minimum and the inductive effect is less damaging.

At this point we must return and pick up the remaining functions of the system. Referring to Fig. 4, note a manual switch position along with the "auto" and "OFF" positions. For manual operation of the primary SCR's, a switch is provided on the front of the control panel. This switch controls the functions of a control board.

10. Manual Control Board (MC)

The manual control board serves as a buffer stage for transmission of the 2500-Hz square wave to the final control switches. Referring to Fig. 12, the signal from the 2500-Hz oscillator is fed into the buffer at the input. The output is applied to the "manual" position, the 2500-Hz square wave is applied to the receiver board, and the final control switches are opened, permitting heater power to flow in the heater circuit.



Pin Connection

A - T6 Output to Receiver
B - T7 Output to Receiver
C - T8 Output to Receiver
D - T9 Output to Receiver
E - T10 Output to Receiver
F - T10 Input from Square-wave Oscillator
H - T9 Input from Square-wave Oscillator
J - T8 Input from Square-wave Oscillator
K - T7 Input from Square-wave Oscillator
L - T6 Input from Square-wave Oscillator
M - Common
N - T5 Input from Square-wave Oscillator
P - T4 Input from Square-wave Oscillator
R - T3 Input from Square-wave Oscillator
S - T2 Input from Square-wave Oscillator
T - T1 Input from Square-wave Oscillator
U - T1 Output to Receiver
V - T2 Output to Receiver
W - T3 Output to Receiver
X - T4 Output to Receiver
Y - T5 Output to Receiver
Z - -27 Volts

ID-103-J5836

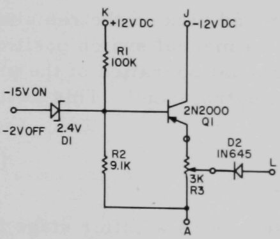
Fig. 12. Manual Control for AC ON-OFF

To turn off the heaters, the switch is simply switched to the open signal position, removing the 2500-Hz square wave.

We have repeatedly mentioned the existence of a setpoint signal without detailing the operation. We will now describe the setpoint function within the circuit.

11. Setpoint Board (SPA)

The setpoint control circuit is shown in Fig. 13. The input is from the inverter. Note the Zener diode used for positive switch action of the 2N2000 transistor. The 2N2000 is either saturated when turned "ON" or far beyond cutoff when turned "OFF." The 2.4-V Zener diode is responsible for these sharp "ON-OFF" characteristics. With the transistor turned "ON," the transistor is saturated, and the 12 V (dc) is essentially dropped across the 3000-ohm variable potentiometer. The tap on the potentiometer is adjusted for the desired setpoint voltage and connected directly to the comparators for comparison with the conditioned input parameter. The IN645 is used in the comparator input leg to isolate between setpoints. Both the 12-V (dc) power supply and the potentiometers are high-quality components to provide a very accurate setpoint voltage.



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Pin Connection

A - Common	N - 2 Potentiometer Wiper
B - 3 Potentiometer Top	P - 3 Potentiometer Wiper
C - 3 Input	R - 4 Potentiometer Wiper
D - 2 Potentiometer Top	S - 5 Potentiometer Wiper
E - 2 Input	T - 6 Potentiometer Wiper
F - 1 Potentiometer Top	U - 4 Potentiometer Top
H - 1 Input	V - 4 Input
J - -12 V DC	W - 5 Potentiometer Top
K - +12 V DC	X - 5 Input
L - Output to Comparitor	Y - 6 Potentiometer Top
M - 1 Potentiometer Wiper	Z - 6 Input

Fig. 13. Setpoint and Pin Connections

In Fig. 4 note four different setpoint controls. These controls perform the following functions:

(1) Setpoint (General)--The pipe-heating system covers many feet of pipe of various sizes and with many different components. The piping and components can be at ambient temperature or at any temperature between ambient and full temperature. If the system heaters were simply energized and heat applied, the pipe and components would vary in the time of heatup because of the mass differences, and sizable mechanical stresses would be applied. To prevent this from occurring, the piping system is heated in increments of temperature so that the low-mass components never exceed in temperature the high-mass systems by more than an allowable limit (50°F). In addition, all sections of the system are not operated at the same temperature.

A 76-point system requires 76 control, 76 high-alarm, and 76 low-alarm setpoints, for a total of 228 points. This would be just too many points to adjust during a heatup of the plant from an ambient temperature of 70 to 580°F in 50°F increments. To provide the operator with a reasonable system, the 76 individual heating systems were arranged in four groups. To each group was assigned a master setpoint control, thereby reducing the operator-required actions from 228 to 12 for each heatup increment. With the switch in the zone position, the control system refers the first 19 signals to setpoint No. 1, or Zone 1 as it is called, and so on for Zones 2, 3, and 4 for increments of 19 input signals. Referring to Fig. 13 for Zone 1, a signal is presented to the input of the 2N2000 and the desired setpoint signal is obtained from the wiper of the 3K potentiometer. After the operating temperature is obtained or as it is approached, individual heater control is more desirable. The switch is then switched from zone to individual.

(2) Individual Setpoint--In this control position each heater section can be individually controlled at any level stated by the operating requirements. To control the heat in each section, the only action required is a simple adjustment of the setpoint potentiometer.

(3) Individual Setpoint (High Alarm)--This assembly of setpoint potentiometers monitors individual heated sections for high temperature.

(4) Individual Setpoint (Low Alarm)--This assembly of setpoint potentiometers monitors individual heated sections for low temperature.

Both the high- and low-alarm circuits monitor for heater or heater-control-system malfunctions. To activate the annunciator, a relay must be driven, which requires high-voltage power. This power is supplied through an alarm-lamp and bell-driver board.

12. Alarm Lamp and Bell Driver (AD)

The alarm unit is a circuit with visual and audible capabilities. It incorporates a reset and acknowledge feature (see Fig. 14).

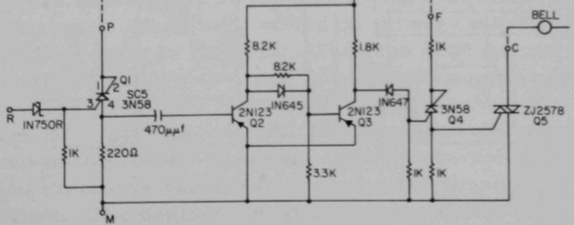

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Fig. 14. Alarm Lamp and Bell Driver

When a logic-level signal of "one" is received at point R, the SCS Q1 is turned on and will stay on until the reset switch is opened. When Q1 turns on, it pulses the pulse shaper, Q1 and Q3. When Q3 turns off, it turns on Q4, which will stay on until the acknowledge switch is opened. Q5 is a "triac," which will be turned on whenever Q4 is on.

The basic components in the measuring circuit have now been covered. We will continue by looking at the timing and sequencing functions.

C. Timing and Sequencing Functions

In the discussion of the measuring-circuit components, the reader may have wondered how the proper setpoint can be selected or how the transistor "AND" board can know which signal is present. The sequencing function can now be discussed with the components of the measuring circuit in mind.

The time response of all components must be considered in a timing circuit because the slowest component defines the fastest speed at which scanning can proceed. In our case, the L & N "M-line" mV/I amplifier is the controlling unit. For complete stability of signal approximately one second is required. This time has been doubled as a safety factor. The dwell time per input is thus 2 sec. The complete scan time for all inputs is 152 sec. Time is controlled by the pulser (see Fig. 4 for the sequence including the pulser).

1. Pulser (P)

This board serves the following functions in a scanning system: (a) manual or automatic advancer, (b) automatic reset of the counter or counters, and (c) automatic point select (see Fig. 15).

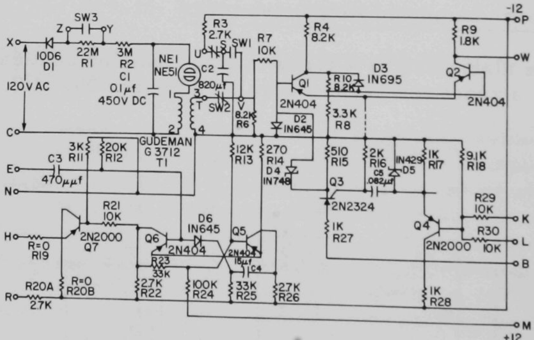

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Fig. 15. Pulser--Auto Reset--Auto Point Select

The manual or automatic advancer is composed of a half-wave rectifier (D1), a resistor-capacitor timing circuit (R1, R2, C1), a firing circuit (NE1), a manual advance (SW1), and a pulse-shaping circuit (R4 through R9, D3, Q1, Q2). The automatic advance timing is determined by the values of R1 + R2 and C1. The timing circuit is charged through D1 until C1 reaches a voltage equal to the firing voltage of NE1. When NE1 fires, pulse is sent to the pulse shaper and out to the input of the decade counter (DC-02-3), advancing it one count. Now C1 is discharged and the cycle is restarted.

The manual advance uses essentially the same method of advancing except that the timing circuit is disconnected by opening SW2, and the firing is obtained by charging C2 through R3 and discharging through SW1 into the pulse-shaping network.

The pulse-shaping network is primarily for use in the manual-advance mode where the SW1 is located some distance from the pulser. With the SW1 located off the pulser board, the inductance of the lead wire can be detrimental to the pulse shape generated from SW1 and C2. The pulse shaper reshapes the pulse into one with a sharp leading edge. In the normal off state Q1 is biased "OFF" and Q2 is "ON." When a negative-going pulse is received at the base of Q1, Q1 begins to turn "ON." Q2 stays "ON" until D3 is reversed, at which time Q2 turns "OFF." The rapid turn-off of Q2 gives the pulse a fast leading edge regardless of the rise time of the pulse at the base of Q1.

The automatic reset circuit consists of R11 through R14, R19 through R26, D1, C3, and Q5 through Q3. In the normal state Q6 is "ON" and Q5 is "OFF." The circuit receives a positive pulse from an inverter turning off Q6, which in turn switches Q5 "ON." This state is maintained until C4 is discharged enough through R25 to turn on Q6. Q5, Q6, and associated components form a pulse-stretching circuit which in turn controls Q6, an emitter follower. Q6 is connected to the reset base of the counters. Q6 is "ON" during the "pulse stretching" time and holds the decade counters in the reset state until Q5 and Q6 return to their normal state.

The automatic point select (R15 through R18, R27 and R28, D2, D4, D5, C5, Q3, Q4, and SW3) is controlled from the collectors of two selected lamp drivers. Q4 is kept turned on through R29 and/or R30 until the preselected point is reached. When the scanner reaches the preselected point, the voltage at K and L approaches zero, turning Q4 "OFF." This pulses Q3 to the "ON" state, clamping the base of Q1 to common through D2. With the base of Q1 clamped to common, the pulse shaper is locked in the "OFF" position. Q3 is a low-voltage SCR and will not turn off until the anode voltage is disconnected through SW3 through contacts not shown. The contacts of SW3 that are shown serve to speed up the pulsing rate of the scanner for point-select mode only. The output of the pulser is fed to the decade counter and the timer in parallel. The circuit through the decade counter will next be traced.

2. Decade Counter (DC)

The decade counter is designed to count 76 pulses. In doing so, it must remember the last pulse counted, reset after each decade, and return to zero after counting 0 through 76.

The heart of the counter is a bistable multivibrator made up of the following components: (a) transistors Q1 and Q2, (b) capacitors C2 and C3, (c) resistors R3 through R6, and (d) diode CR1. Referring to Fig. 16, note that there are four such units.

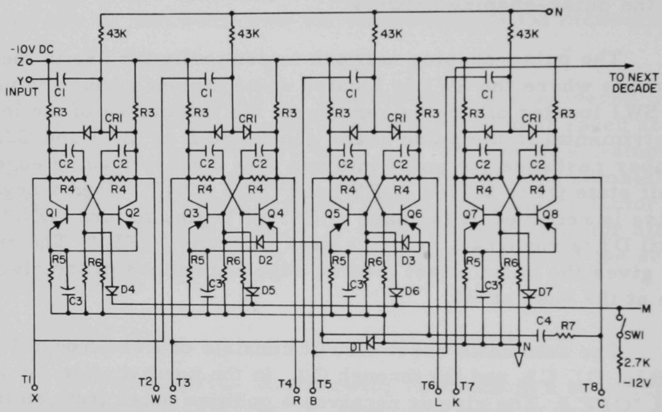

Fig. 16. Decade Counter

As was pointed out previously, in a bistable multivibrator normally one of the two transistors is "ON," the other is "OFF." In this circuit, the input pulse is fed to the first-stage bistable at point Y. Depending on which transistor is "ON," the positive input pulse will turn the "ON" transistor "OFF," and the "OFF" transistor will then turn "ON," following the signal coupled to it through capacitor C2. The third pulse from the pulser switches the transistors to the original state and also sends a pulse to the next stage. By tracing the circuit through the succeeding stages, you will note that resistor R7, capacitor C4, and diodes D1 through D3 form a feedback network. This feedback network changes this basic "count by 16" counter to a "count by 10" counter by adding 6 additional counts for each 10 pulses received from the pulser.

The count information is fed from the decade counter to a diode matrix by monitoring the state (ON-OFF) of each of the transistors in the bistable multivibrator.

3. Diode Matrix (D)

The diode matrix is shown in Fig. 17. The purpose of the diode matrix is to decode the counter information and transmit the decoded information to the following stage. The diode matrix also acts as a load for the decade counter, isolating it from the system.

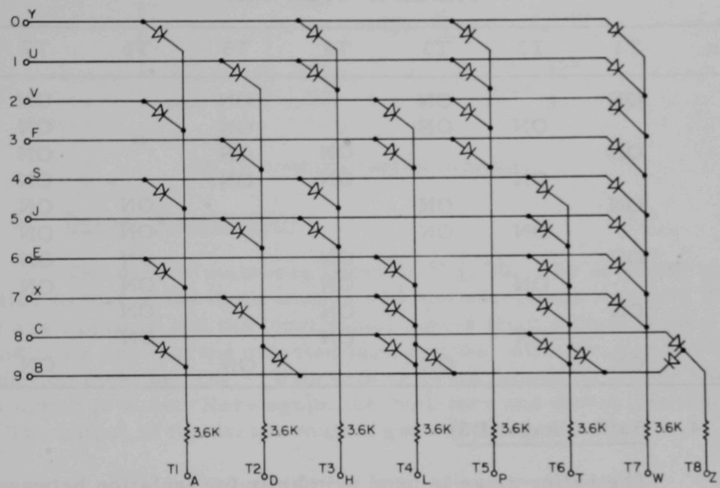

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Fig. 17. Diode Matrix

For any given number 0 through 9, four conditions must be satisfied. The conditions are identified by the status of the eight transistors in the decade counter. Referring to Fig. 17, note that each number bus 0 through 9 has four diodes connected to it. To actuate the next stage, a bus must be at the "zero" state, which can only occur when all four diodes connected to a particular bus are fed from an "ON" transistor in the decade counter. If any of the diodes see an "OFF" transistor, the bus is at "one" potential and inactive. Table I is a "truth" table and states the condition of each of the eight transistors in the decade counter. Note in Fig. 17 that transistor T1 has diodes connected to the number buses 0, 2, 4, 6, and 8. Transistor T1 thus has a potential for turning "ON" numbers 0, 2, 4, 6, and 8. Note also the different combinations of number buses and transistors. Assume, for example, that the decade counter is in the zero position. From the "truth" table we find that transistors T1, T3, T5, and T7 are "ON." Returning to Fig. 17, note that the 0 bus had diodes connected to it from transistors T1, T3, T5, and T7. Bus 0 is at the "zero" state and will transmit to the next stage. Note diodes connected to bus 1 from transistors T2, T3, T5, and T7. Of these, T2 is "OFF;" therefore, bus 1 is at the "one" stage and will not transmit to the next stage. Note diodes connected to bus 2 from T1, T4, T5, and T7. Of these, T4 is "OFF" and bus 2 is at state "one." By referring to the "truth" table and the matrix drawing, it will be seen how each pulse from the pulser is counted and used as the base for time and/or system alignment. The output of the diode matrix is fed to a buffer stage.

TABLE I. Truth Table

Counts	T1	T2	T3	T4	T5	T6	T7	T8
0	ON		ON		ON		ON	
1		ON	ON		ON		ON	
2	ON			ON	ON		ON	
3		ON		ON	ON		ON	
4	ON		ON			ON	ON	
5		ON	ON			ON	ON	
6	ON			ON		ON	ON	
7		ON		ON		ON	ON	
8	ON			ON		ON		ON
9		ON		ON		ON		ON
0	ON		ON		ON		ON	

4. Buffer Stage (BS)

The buffer stage is used primarily for isolation between the diode matrix and the inverters which follow the buffer stage. Additionally, the output of the diode matrix is inverted in the buffer stage (see Fig. 18). This output signal is then fed to the lamp driver.

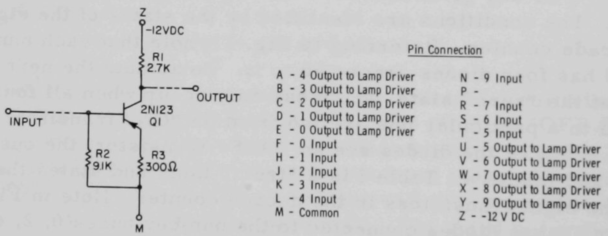

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Fig. 18. Buffer Stage and Pin Connections

5. Lamp Driver (LD)

The lamp driver is shown in Fig. 19. The lamp to be energized is a 327 lamp used for channel identification. The 2N2000 transistor is either saturated when turned "ON" or far beyond cutoff when turned "OFF." The 2.4-V Zener diode is used for sharp "ON-OFF" characteristics. The next stage is the decade matrix.

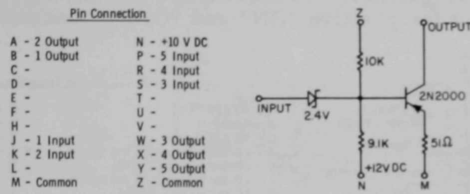

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Fig. 19. Lamp Driver and Pin Connections

6. Decade Matrix (DM)

The decade matrix is shown in Fig. 20. The decoding operation is similar to that of the diode matrix with the exceptions that only two conditions are required and the input signal comes from a lamp driver. The two conditions are that the selected lamps in the units position and in the tens position must be "ON." With both selected lamps "ON," the decade matrix output is zero. Here again, the resistors and diodes prevent feedback. The output of the decade matrix goes to the inverters.

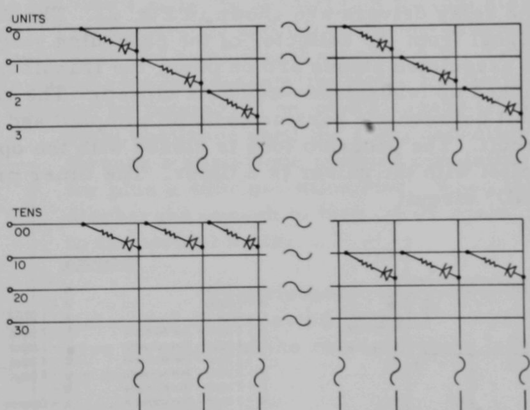

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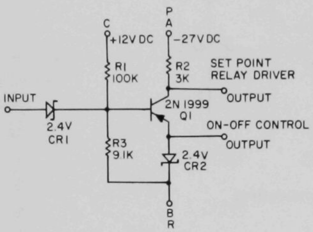
Fig. 20. Decade Matrix

7. Inverter (IS)

The inverter is shown in Fig. 21. The input to the inverter comes from the decade matrix. For an inverter to have an input the decade counter must be on that particular point. Normally (off-point), the inverter is "ON." The inverter performs the following functions in the circuit: (a) control for the setpoint and relay drivers that follow in the system, and (b) control for the "ON-OFF" control board (CB board). The inverter stage employs the sharp "ON-OFF" characteristics of the 2.4-V Zener diode on the input for positive "ON" and "OFF" conditions.



Pin Connection

A - -30 V DC	N - 3 Input
B - Common	P - -27 V DC
C - +12 V DC	R - Common
D - 2 Output to Relay Driver and Setpoint	S - +12 V DC
E - 2 Output to ON-OFF Control	T - 4 Output to Relay Driver and Setpoint
F - 1 Output to Relay Driver and Setpoint	U - 4 Output to ON-OFF Control
H - 1 Output to ON-OFF Control	V - 5 Output to Relay Driver and Setpoint
J - 3 Output to Relay Driver and Setpoint	W - 5 Output to ON-OFF Control
K - 3 Output to ON-OFF Control	X - 4 Input
L - 2 Input	Y - 6 Input
M - 1 Input	Z -

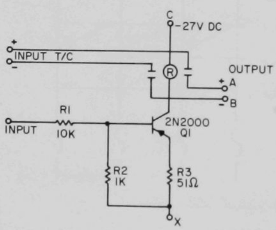
ID-103-J5860

Fig. 21. Inverter and Pin Connections

The output of the inverter is taken to the collector for the relay drivers and to the emitter for the "permit" signals required in the balance of the system.

8. Relay Drivers (RDR)

The relay drivers are shown in Fig. 22. The 2N2000 transistor receives its signal from the collector of the preceding stage. When the pulser and the associated stages are on point, the transistor is "ON" and the relay is picked up (energized--contacts closed). The relay contacts close the circuit between the parameter to be sampled and the input-measuring circuit. The program loop is closed with the operation of this relay. In parallel with the pulser is a timer. The timer programs the transistor "AND" circuit.



Pin Connection

A - + Output	N -
B - - Output	P -
C - -27 V DC	R - 1 Input
D - 4 Input + Thermocouple	S - 2 Input
E - 4 Input - Thermocouple	T - 3 Input
F - 3 Input + Thermocouple	U - 4 Input
H - 3 Input - Thermocouple	V - 5 Input
J - 2 Input + Thermocouple	W -
K - 2 Input - Thermocouple	X - Common
L - 1 Input + Thermocouple	Y - 5 Input - Thermocouple
M - 1 Input - Thermocouple	Z - 5 Input + Thermocouple

ID-103-J5859

Fig. 22. Relay Driver and Pin Connections

9. Timer Circuit (T)

The timer circuit (see Fig. 23) is used to delay the final switching action until the measuring-circuit mV/I converter has had time to balance. Without this delay, the heaters would change state following the balancing sequences of the mV/I converter. The timer circuit employs solid-state components and has a range from 0 to 10 sec. The timer output has logic levels of zero and one, and the time cycle is initiated by a negative pulse.

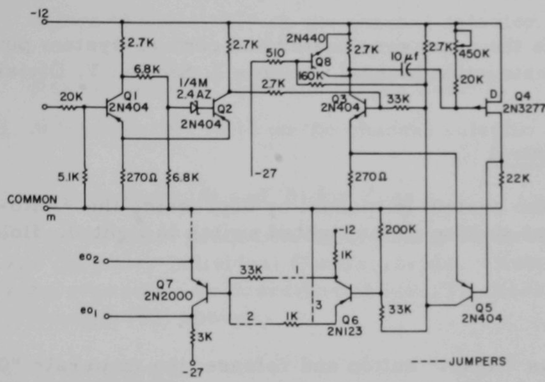


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Fig. 23. Timer Circuit

When the timer is in the normal (not timing) state, transistors Q1, Q3, and Q6 are on. Transistors Q1 and Q2 comprise an amplitude reception circuit and fire only when the input signal exceeds 5 V. Transistors Q3, Q4, and Q5, and their associated components comprise the timing cycle. The timing cycle is initiated by turning Q3 on, which causes Q5 to turn off. This state continues until the 10-μf capacitor has discharged through a resistance network consisting of a 20K resistor plus a 450K potentiometer. When the capacitor discharges enough to turn Q4 on again, the timer returns to its normal state.

Transistor Q6 is a buffer stage for the timer and is connected to the Q7 output transistor to give an output of the required logic level, i.e., zero or one.

10. Diode "OR" Board (DO)

A special board was necessary for programming the zone setpoint. It is included here only for completeness (see Fig. 24).

The diode "OR" circuit is a circuit in which two or more signals can be joined without feedback. The input comes from the collector of the inverter and the output goes to zone setpoint.

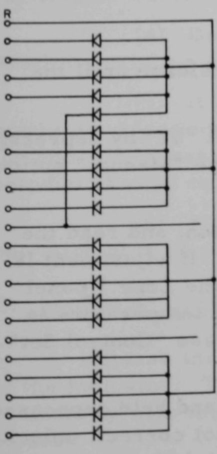

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Fig. 24. Diode "OR" Circuit

V. DIRECT OPERATING PROCEDURES

Outlined below are the procedures for putting the control system in operation.

A. Power

Provide the necessary heater and control-system power as outlined in Operating Instruction Manual, Volume 2, Section V, Division D, pages D-2 and D-3.

B. Manual Control

Place the system in manual by depressing the "Auto-Man" button until the manual section of the lighted switch is lighted. Hold button depressed.

C. Reset

Depress "Reset" button and release; the numerals "00" should appear in the channel identification windows.

D. Control and Alarm Setpoint Procedure

1. Zone Control

(Note: The zone control is a feature added for the convenience of the operator during controlled heat-up or cool-down of the system. The advantage gained is the saving of time in resetting the control and alarm setpoints in groups of twenty instead of individually.)

(1) Depress "Zone-Individual" button and release until the zone part of the indicator lights.

(2) Advance the scanning system to channel "01" by depressing and then releasing the "Manual Scan" button. (Note: The "Manual" button must be held depressed for "Manual Scan.")

(3) Depress and hold the "Control Set" button, and read the "Analog" readout for the existing setpoint temperature. If adjustment is required, unlock the duo-dial potentiometer control on the Zone 1 panel board. Turn clockwise or counterwise until the desired temperature is read on the "Analog" readout. Lock the duo-dial. Release "Control Set" pushbutton only.

(4) Depress the "Alarm Set--High" button and held depressed while reading the "Analog" readout. If the setpoint is not correct, unlock the duo-dial and adjust the potentiometer until the desired alarm point is read on the "Analog" readout. Release "Alarm Set--High" and "Auto-Man" buttons.

(5) Select channel "21" on the channel selector by switching to "ON" the "20" and "01" switches. Depress the "Auto-Man" button and hold depressed. Depress the point-select button and hold depressed until "21" appears in the "Channel Identification" window.

(6) Repeat setps (3), (4), and (5) for Zone 2.

(7) Select channel "41" on the channel selector and repeat step (6).

(8) Repeat setps (3), (4), and (5) for Zone 3.

(9) Select channel "61" on the channel selector and repeat step (6).

(10) Repeat steps (4) and (5) for Zone 4.

(11) For setpoint procedure on channels 61 through 76, see steps (4), (5), and (6) under Individual Control, below. (Note: The alarms are all set by zone procedure as described above. To check alarm setpoints repeat steps (1) through (11) above).

2. Individual Control

(1) Depress the "Zone-Individual" button until the "Individual" part of the indicator lights.

(2) Place "Auto-Man" button in "Man" position by depressing and holding depressed. The "Man" light will be lighted.

(3) Advance the scanning system to "01" by depressing reset button and releasing and depressing and releasing "Manual Scan" button. Numerals "01" should appear in the "Channel Identification" window.

(4) Depress and hold depressed the "Control-Set" button. Read the existing setpoint on the "Analog" readout meter.

(5) If an adjustment is required, uncover individual setpoint potentiometers located in the lower left (west) part of the panel. Unlock the duo-dial operator for potentiometer "01." Adjust until the desired setpoint is read on the "Analog" readout. Lock the potentiometer operator.

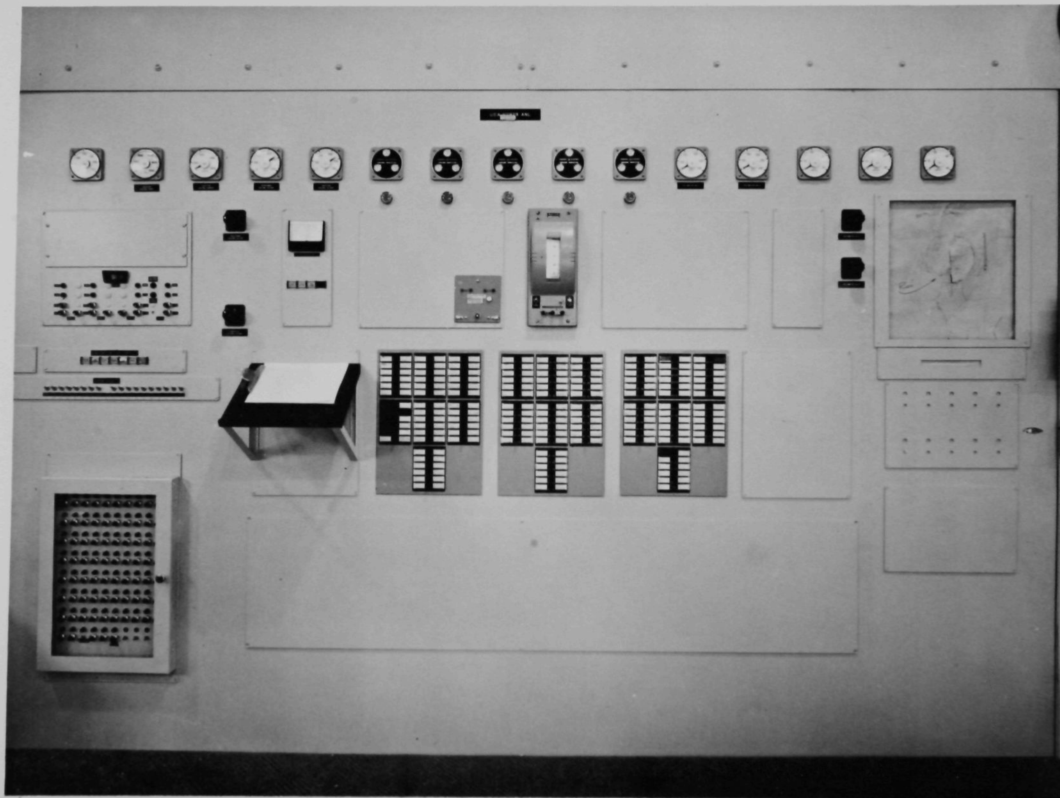
(6) Advance to channels "02" through "76," setting each potentiometer as required.

E. Automatic Control

Release the "Auto-Man" button to obtain "Auto" in the lighted part of the indicator. The system is now on automatic control, controlling in conformity with the setpoints in either the "Zone" or "Individual" control modes.

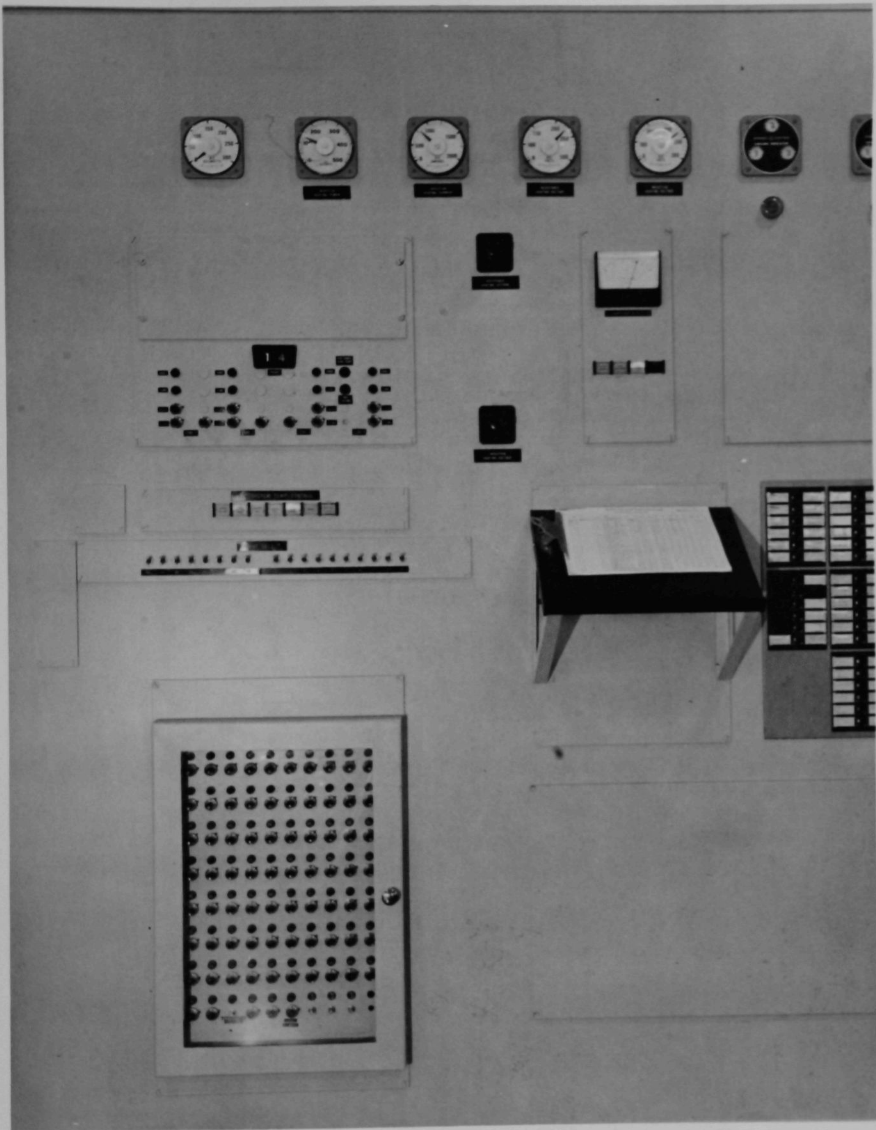
APPENDIX A

Photographs of Trace Heating System



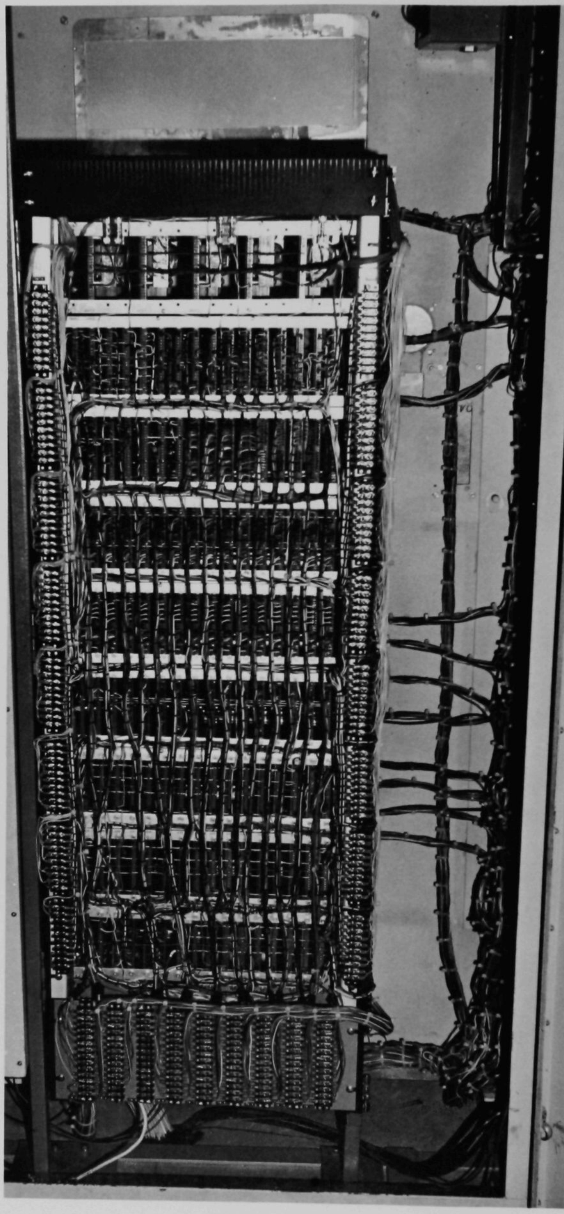
ID-103-H5950

Fig. 25. Front View of Trace Heating Control Section



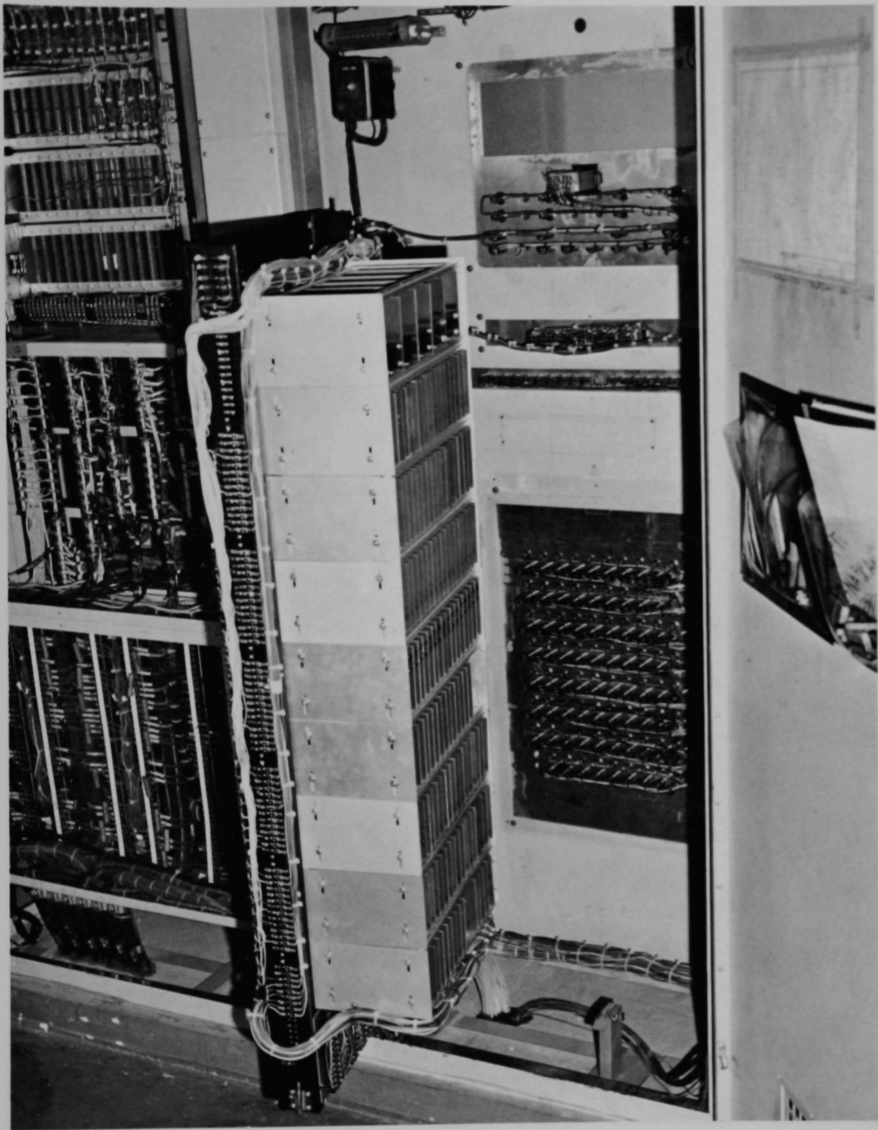
ID-103-15866

Fig. 26. Front View of Control Panel Showing Scanner Controls and Setpoint Potentiometers



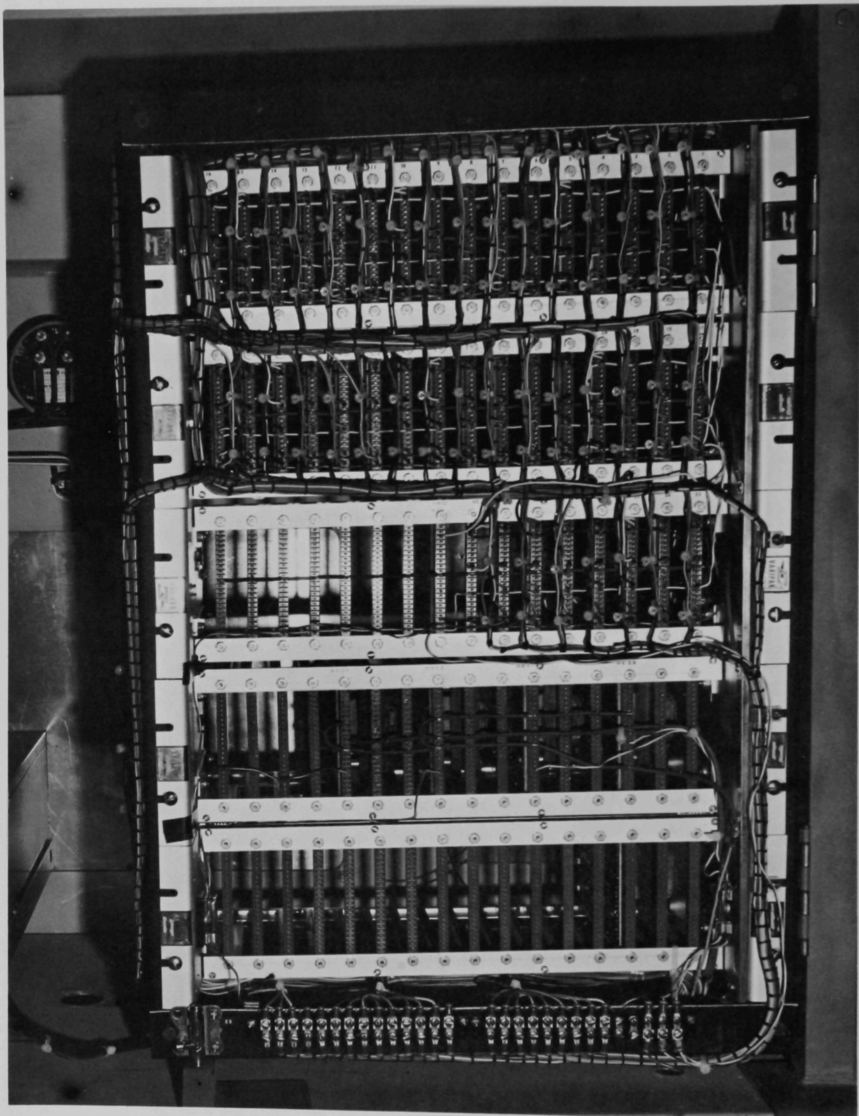
ID-103-H5122

Fig. 27. Rear View of Control System Showing Scanner and DC Control Units



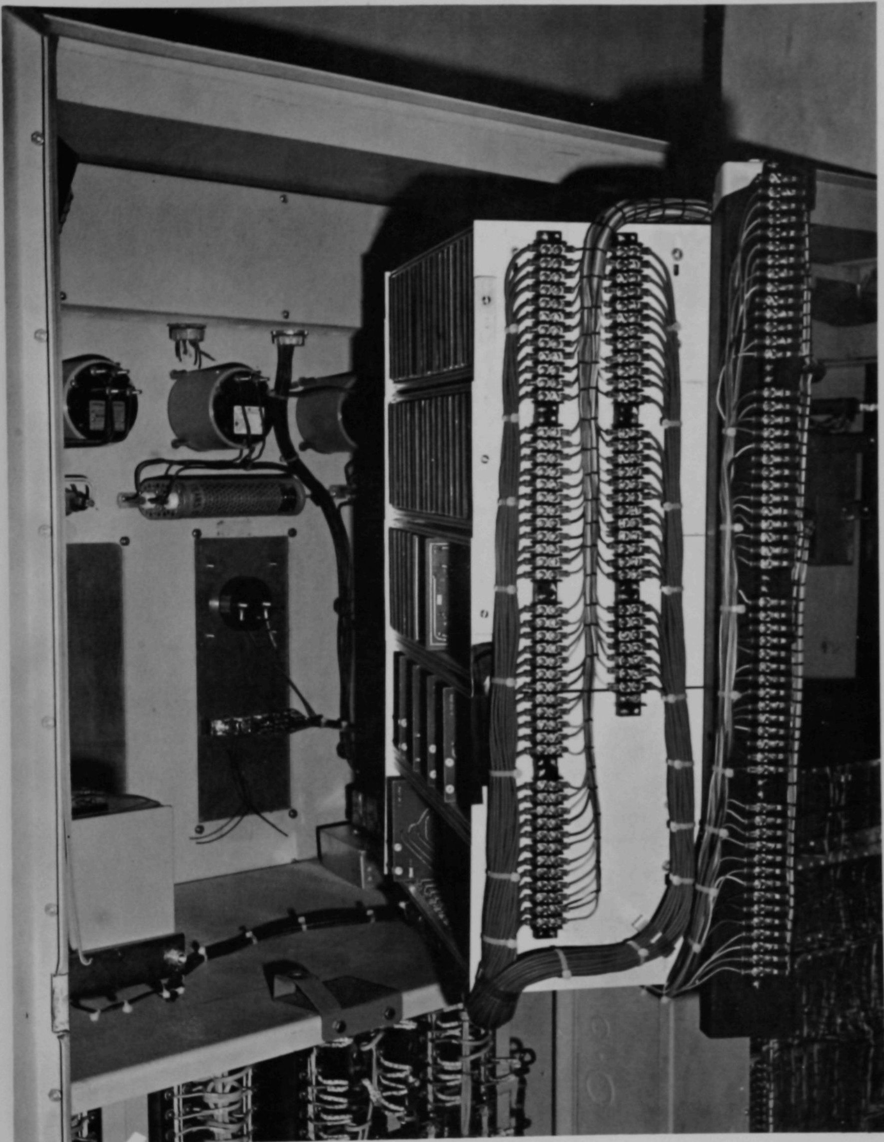
ID-103-H5126

Fig. 28. Same View as Fig. 27 with Printed Circuit Chassis in the "Opened" Position



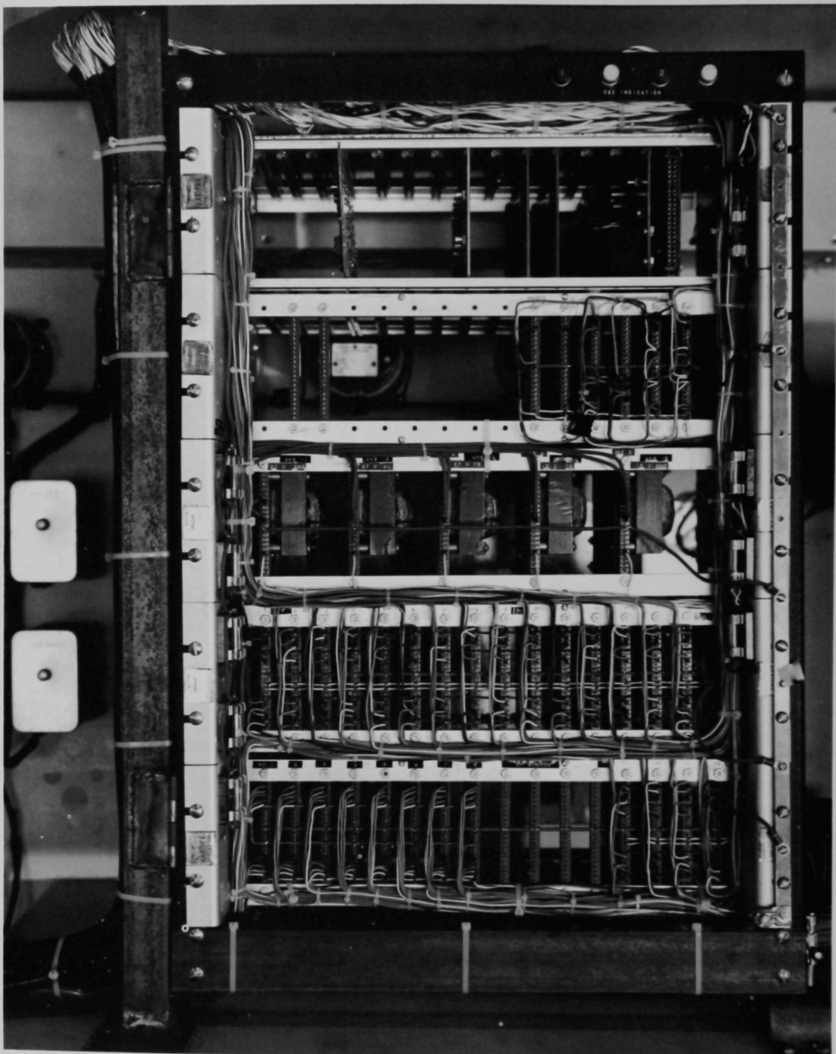
ID-103-H5123

Fig. 29. Rear View of Control System Showing Power Supplies and AC Control Cards for Indicator Lights



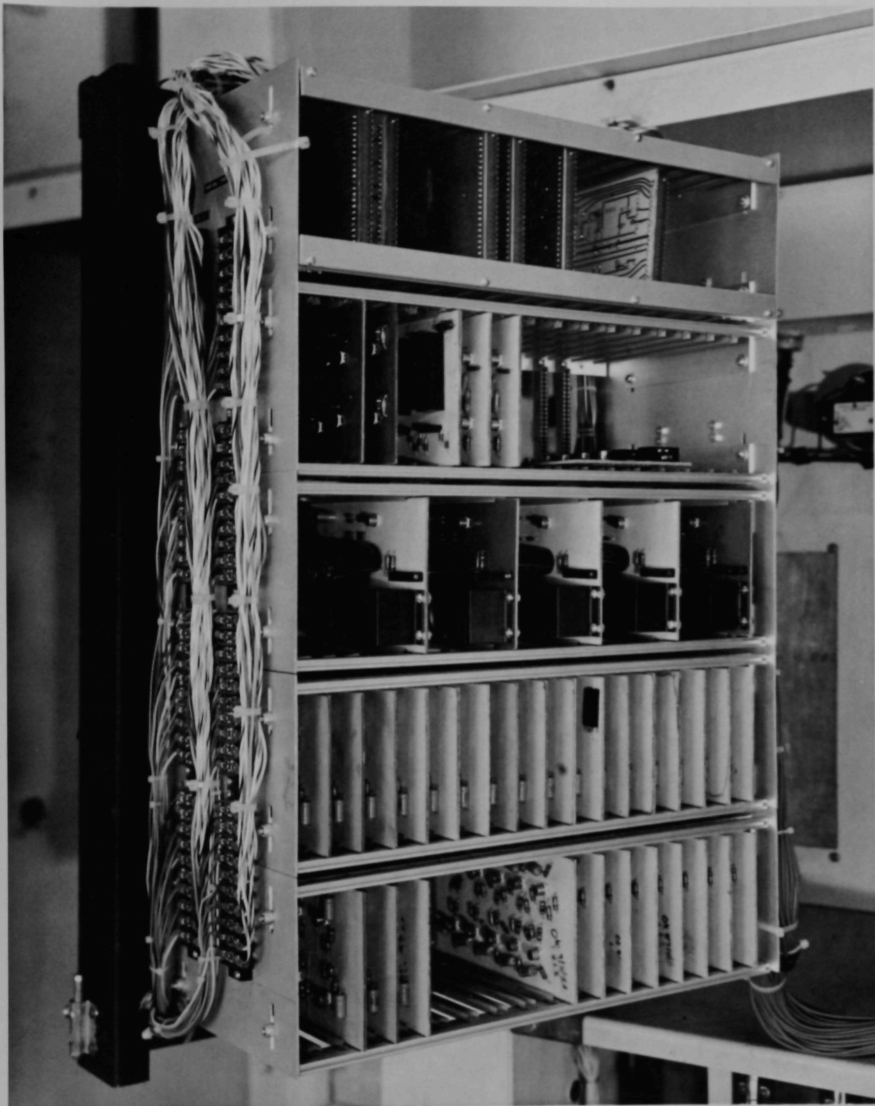
ID-103-H5124

Fig. 30. Same View as Fig. 29 with Card Rack in the "Opened" Position



ID-103-I5865

Fig. 31. Rear View of Control System Showing 2500-Hz Transmitters, Square-wave Oscillators and Manual Control Cards



ID-103-I5864

Fig. 32. Same View as Fig. 31 with Card Rack in "Opened" Position

ID-103-H5949

Fig. 33. View of West Section of SCR's and Receiver Boards